# Advanced Accelerator Applications Technical Quarterly Review

**(Covering January-June 2002)**

## LBE-Related Technology

**WBS 1.25.04**

**Ning Li**

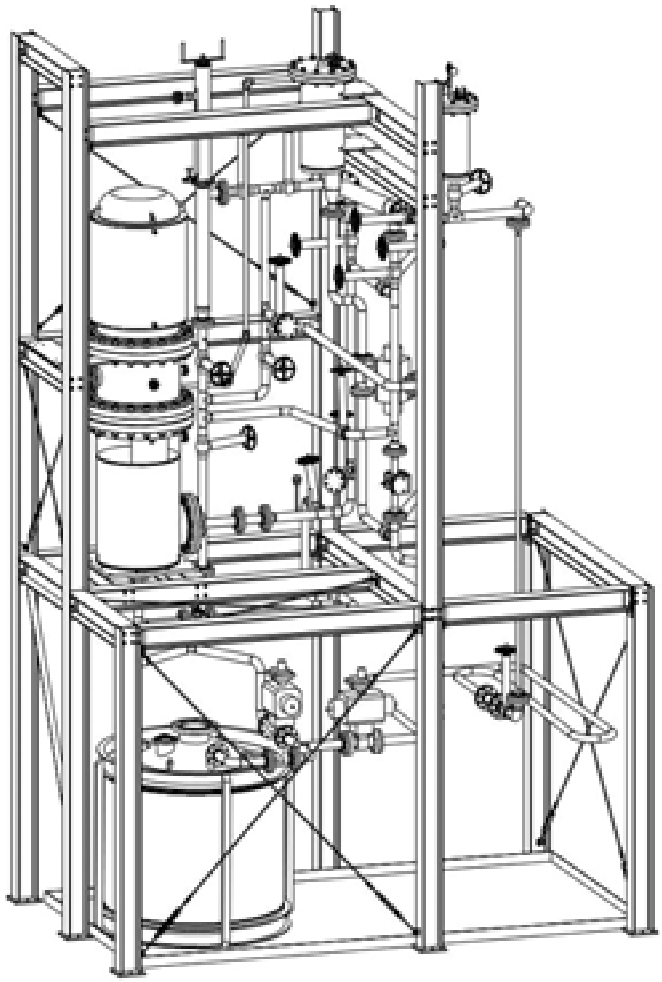
**July 10, 2002**

Advanced Accelerator Applications

# *Milestone Performance in 2nd-3rd Quarters, Jan.-June, FY02*

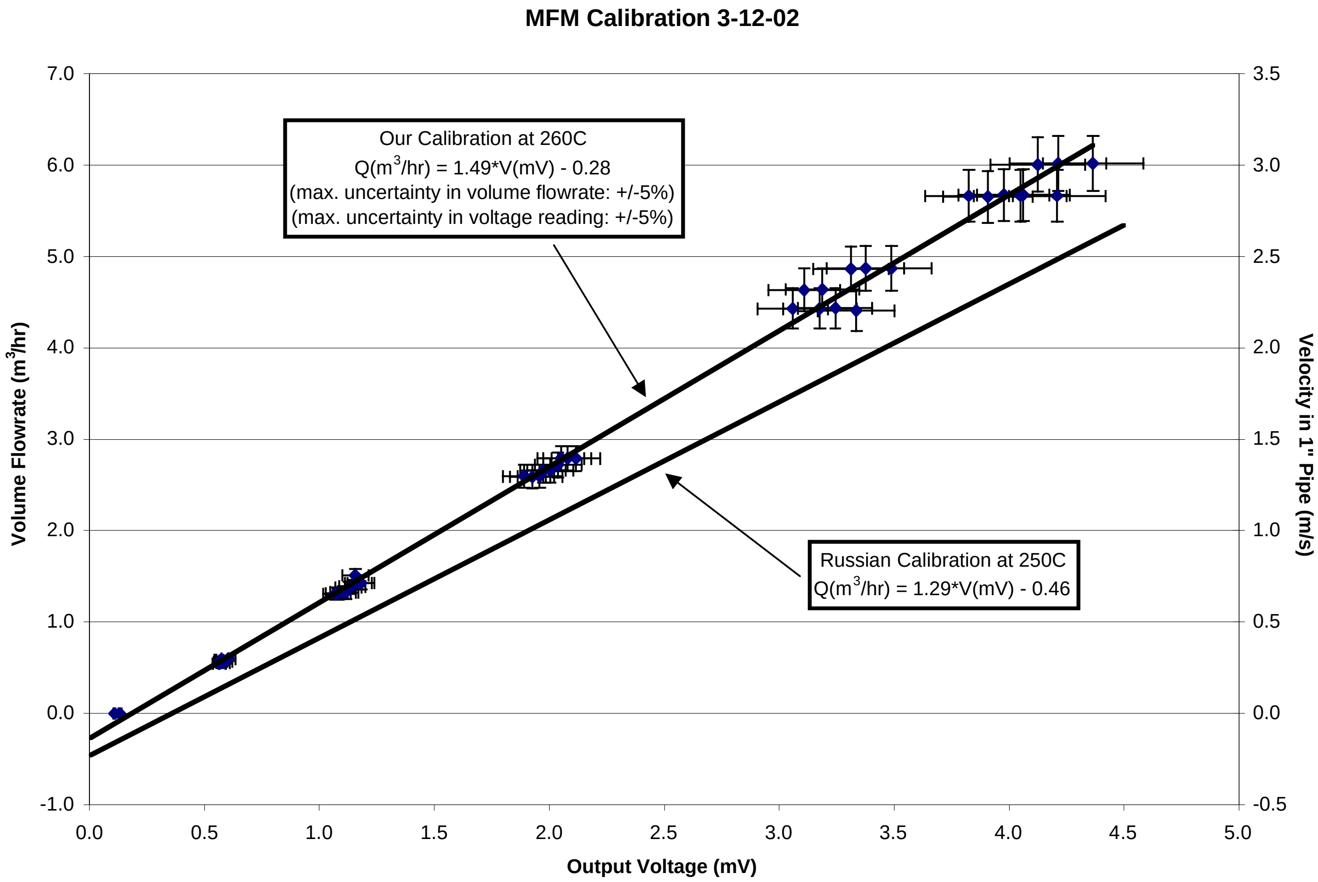
| **Milestones** | **M/S Level** | **Baseline** | **Status** |
|---|---|---|---|
| Receive oxygen sensors for unattended operations | 3 | 4/11/02 | Ahead of schedule |
| Issue oxygen control and calibration strategy report | 3 | 5/31/02 | On time |
| Complete operational tests including sensor calibrations | 3 | 4/29/02 | Delayed: various small defects, delays and improvements; will be ready for corrosion test before August |
| Approval of unattended operations | 2 | 4/29/02 | Ahead of schedule |

# *Highlights for DELTA Loop Operations Jan.-June, FY02*



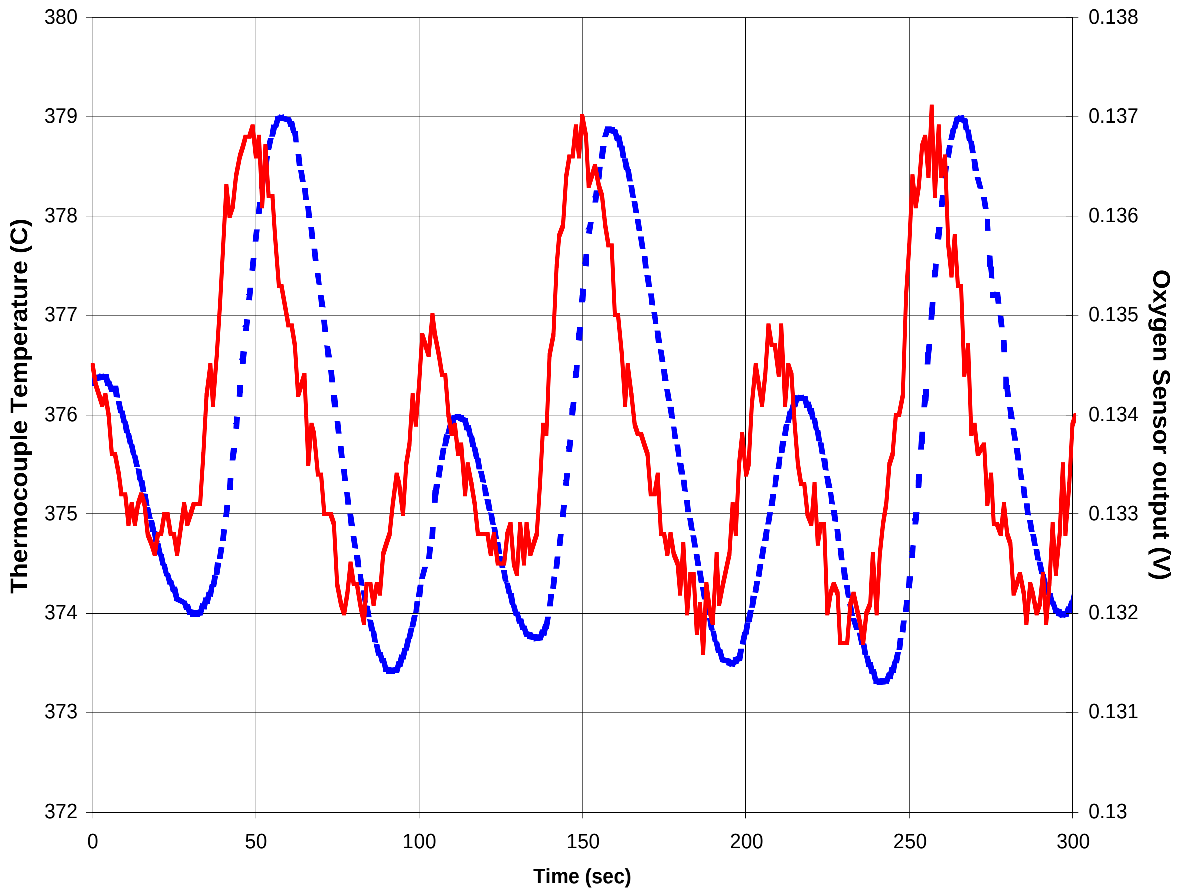
- Operated for over 70 hours at temperatures up to 400ºC
- Stable output from the oxygen sensors
- Variable flow speeds up to 35GPM ($8 m^3/hr$)
- Natural convection flow at $1 m^3/hr$
- Operated in isothermal regime and and with temperature gradient
- Unattended operations approved and under testing
- Upgraded and tested cleaning gas injection system including forming and melting the freeze plug and maintaining constant cleaning gas pressure
- Data acquisition and control system including shut down controls proved reliable

# *Magnetic Flow Meter Calibration*




Advanced Accelerator Applications

# *Stable Oxygen Sensor Output at Expected Values in DELTA Loop*



# *Unattended Operations of DELTA Approved and Under Testing*

- DELTA loop design and operation underwent a readiness review and received authorization to run unattended on April 25$^{th}$

- The following conditions are implemented as part of unattended operations
  - Interlock and other safety controls are tested periodically.
  - HCP and procedures ensure control of safety settings such as max/min temperatures.
  - Autodialer notifies system operators of shut down conditions.
  - Remote viewing of the operational data is available

# *FY02 Corrosion Test Plan Finalized*

- Objectives
  - Operation performance test for extended unmanned test operations with oxygen control
  - Short term test of MEGAPIE window candidate materials and several variations of alloys and surface treatment

- Goals
  - Achieve stable test operations with oxygen control over extended period
  - Provide performance data for the MEGAPIE window candidate materials for one specific (slightly more stressed) condition
  - Provide data to understand the protective oxide growth and repair mechanisms and kinetics

# *Materials Selection to Meet Programmatic and Scientific Objectives*

- Programmatic (corrosion and tensile specimens)
  - T91 (MEGAPIE window candidate material), HT-9 (alternative)
  - EP823 (reference Russian alloy)
  - 316L (base material for LBE systems)
  - T91/316L weld (MEGAPIE design)

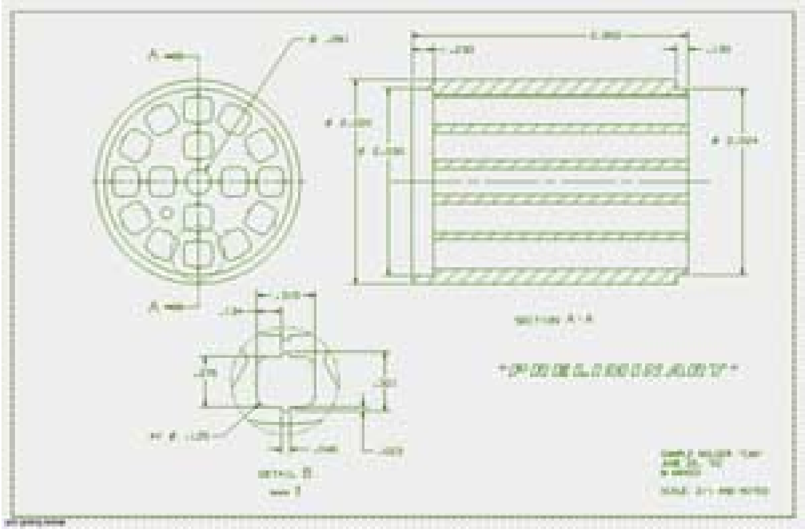
- Scientific (corrosion specimens)
  - Ta
  - Si-Fe alloys (role of Si for enhanced corrosion resistance)
  - CEA Al-316L, FZK GESA-treated 316L (surface treatment)

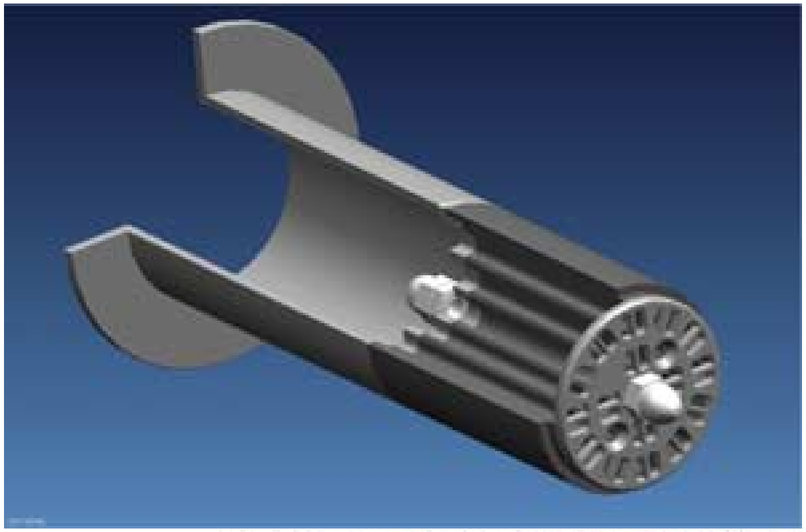
# *Temperature and Flow Conditions: Slightly More Stressed than MEGAPIE*

- Temperature
  - 500ºC max, 100ºC gradient (MEGAPIE $T_{in}$ ~240, $T_{out}$~340, $T_{win,max}$~380ºC)
- Flow
  - 2 m/s - max design limit before onset of erosion (MEGAPIE $V_{max}$ < 1.5 m/s)
- Oxygen Control
  - $10^{-6}$ wt% - mid-range of oxygen control regime
- Time Intervals
  - 333, 667, 1000 hours

# *Specimens and Holders in Fabrication*

- Corrosion and Tensile Specimens
  - 8mm W x 35mm L x 1mm T
- Sample Holder Design and Specimen Arrangement Finalized
  - Each holder holds 32 specimens
  - 6 holders arranged in series in the test section
  - CFD-aided design to homogenize flow distribution
  - Entrance flow conditioning via extra 3 holders and specimens upstream





# DELTA Plan for Rest of FY02 and FY03

- 333 hour, 667 hour and 1000 hour material tests will be conducted before the end of the fiscal year
- Corrosion probes will be designed for and tested (FY03) in the loop
- More long term materials tests will be planned for FY03 (with extension of test temperature)
- Extension of capability for erosion/corrosion tests will be planned FY03
- Thermohydraulic tests will be planned for FY03
- New flow measurement techniques will be investigated

# *Developing Integrated Test Plan for LBE Technology Development*

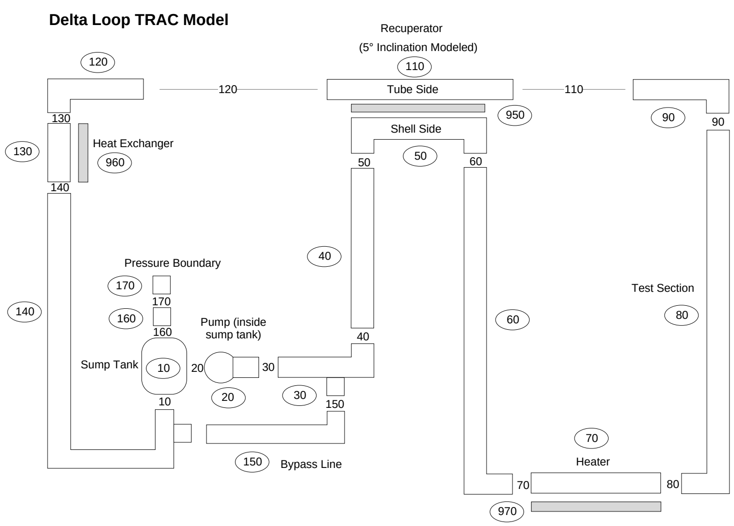
- Program Drivers
  - ADS/Transmutation: US ATW/AAA, EU P&T(MEGAPIE, XADS, MYRRAH), Japan P&T, S. Korea HYPER
  - Advanced Reactors: US NERI/NEER/Gen IV, GIF, Japan FR Commercialization, EU MICA/"Michelangelo"

- R&D Facilities
  - US: LANL DELTA Loop and LBE technology development experiments, UNLV TC-1 and lab, small loops/experiments at ANL, INEEL, MIT
  - Germany: FZK KALLA and associated labs
  - France: CEA CICLAD, CNRS small experiments
  - Switzerland: PSI LiSoR
  - Japan: JAERI, TIT loops and experiments
  - Russia: Loops and labs
  - Italy: ENEA/Ansaldo CIRCE
  - Spain: CIEMAT small experiments
  - Sweden: RIT loop

# *LBE R&D Facilities and Program Focus*

| Organization | Facility | Capability | R&D Focus | Status |
|---|---|---|---|---|
| LANL, US | DELTA Loop (LBE technology development experiments) | Oxygen control, T<550$^o$C, v<5m/s, V~0.35m$^3$, 100kW effective heating, natural convection, large and flexible test section | Materials and thermal hydraulic testing (Oxygen sensor, control, calibration, corrosion modeling, corrosion probes, UDV etc) | Operational |
| UNLV, US | TC-1 | EMP, V~0.068m$^3$, 600kW heat removal capacity | Benchmarking experiments for materials, heat transfer and thermal hydraulic studies | Delivered |
| FZK, Germany | THESYS(1) THEADS(2) CORRIDA(3) (supporting labs) | Oxygen control, T<550$^o$C, (1) V~0.1m$^3$, EMP, (2) V~4m$^3$, 4MW heating, (3) V~0.03m$^3$, sampling ports, in-situ mechanical tests | (1) Technology development, (2) thermal hydraulic testing, (3) corrosion testing | (1) Operational (2) Start '02 (3) Start '03, extend to T<650$^o$C |
| CEA, France | CICLAD (static test experiments) | Low oxygen, EMP, rotating cylinder, $v_s$<6m/s ($v_f$<0.1m/s), T<650$^o$C | Corrosion testing (surrogate spallation products) | Operational |
| ENEA/Ansaldo, Italy | CIRCE | Pool test, T<550$^o$C, 90 T LBE, natural and enhanced circulation, 1MW heating | Engineering testing | Operational |
| RIT, Sweden | Loop | | Natural convection and heat removal from reactor core | Under construction |
| TITech, Japan | Loop | Oxygen control, T<550$^o$C, v<2m/s, V~0.022m$^3$, 22kW heating | Corrosion testing | Operational |

# *Highlights for LBE Technology Development Jan.-June, FY02*

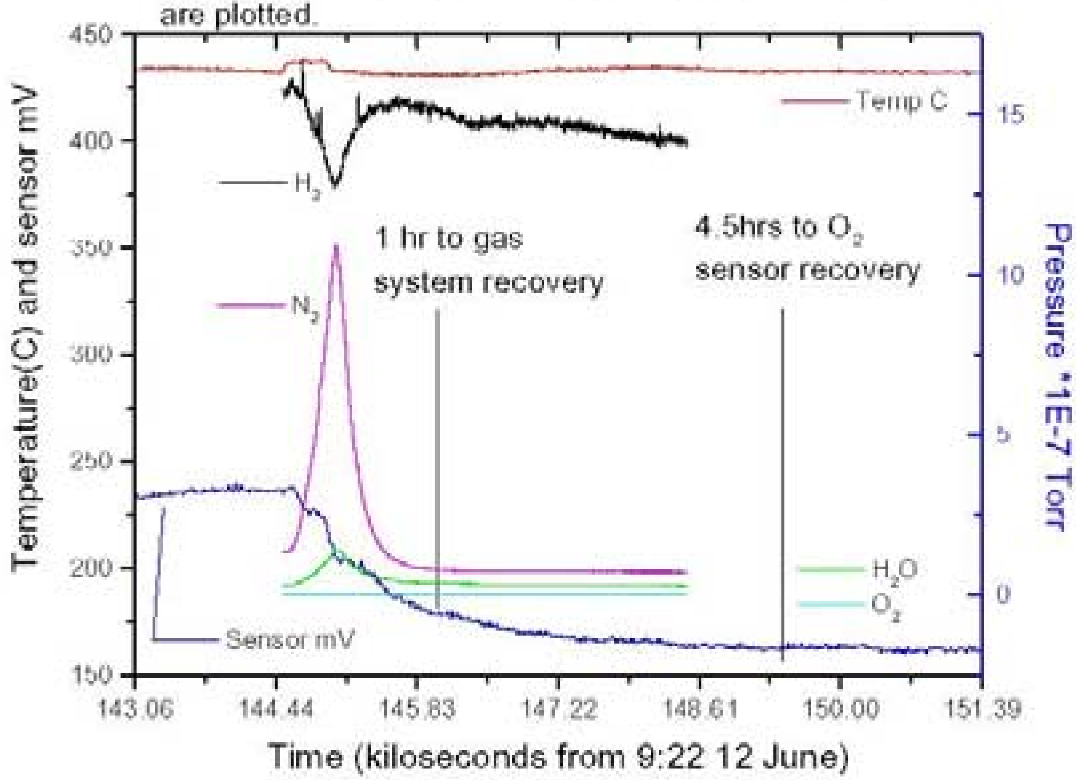



- Oxygen Sensors installed in DELTA
- Start of hydrogen/steam mixture system to calibrate oxygen sensors
- Oxygen control methodology and calibration strategy report issued
- Corrosion modeling improved the model prediction and mapped the average corrosion rate of DELTA Loop (2 papers under preparation)
- A TRAC model for DELTA established to benchmark the modification incorporating LBE features (validated TRAC will be used to support MEGAPIE safety studies)

Advanced Accelerator Applications AAA

# *Testing Oxygen Sensor Calibration System*

Characteristics of an air leak in the calibration system. Gas pressures (via RGA), sensor voltage and temperature are plotted.



# *Gas Phase Oxygen Control Methodology*

- Gas Phase Oxygen Control
  - Direct injection of oxygen and hydrogen into either LBE or cover gas over flowing LBE surface (implemented in DELTA Loop)
  - Injection of hydrogen/steam mixture that will produce the desired oxygen level at equilibrium (in testing for sensor calibration)
- Advantages
  - Simple design
  - Gas in/gas out
  - Hydrogen/steam mixture can be used for calibration
  - Hydrogen at high throughput can be used for sparging and restoration of LBE systems
- Disadvantages
  - Gas line pressure regulation needs to be carefully design for and controlled
  - Gas/liquid mass exchange is not efficient
  - Prone to excess slag formation

# *Solid Phase Oxygen Control Methodology*

- Solid Phase Oxygen Control
  - Solid lead/bismuth oxide spheres in a porous container in a bypass
  - Release controlled via temperature, flow and duration
  - Possible use of solid hydride for cleaning
- Advantages
  - Efficient mass exchange
  - Little slag formation, less coolant contamination
- Disadvantages
  - Oxide inventory limited
  - More R&D needed to prove performance

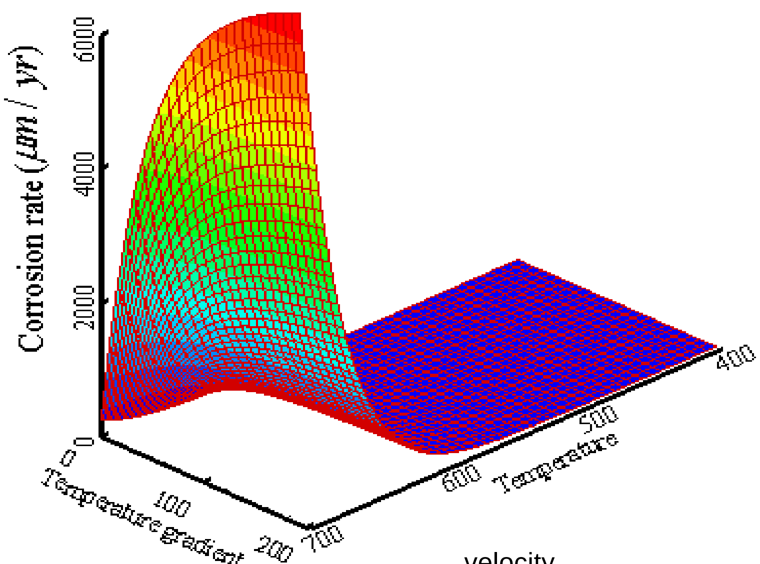
# Oxygen Sensor Calibration Strategy

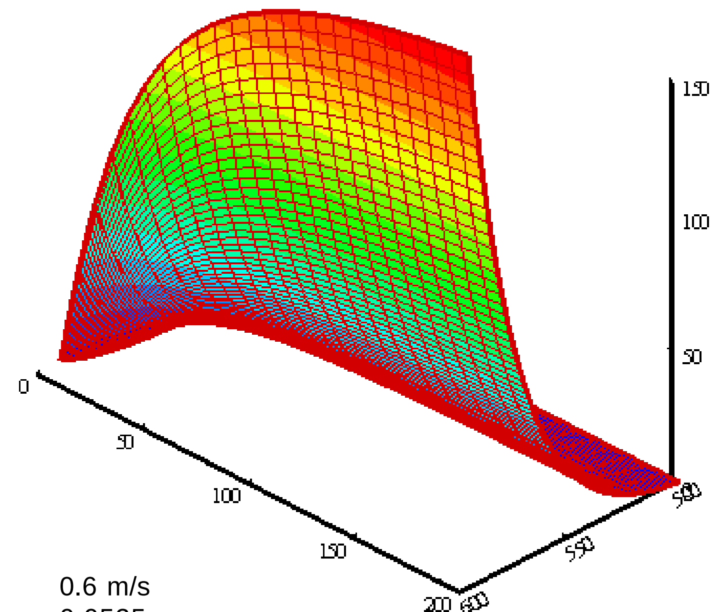
- Oxygen Sensor Calibration Strategy (Standard)
  - Using hydrogen/steam mixture to attain absolute partial pressure of oxygen in the desired range (also adopted by CEA, FZK and TECLA)

- Alternative Strategies
  - Using solubility limit of oxygen in LBE for one set of curves (relying on IPPE solubility data)
  - Using oxide dissociation limits (NiO, $Fe_3O_4$, $Cr_2O_3$, etc)
  - Cross-calibrate sensors with various reference electrodes (Bi/$Bi_2O_3$, In/$InO_2$, Pt/air)

# *Progress on Modeling System Corrosion*

- Improvement of the mass transfer coefficient based prediction of corrosion rate in test loops (incorporate the effect of bulk concentration of corrosion product through system calculation)
- Mapping of the (average) corrosion rate as a function of the hot test section temperature and temperature difference in DELTA Loop



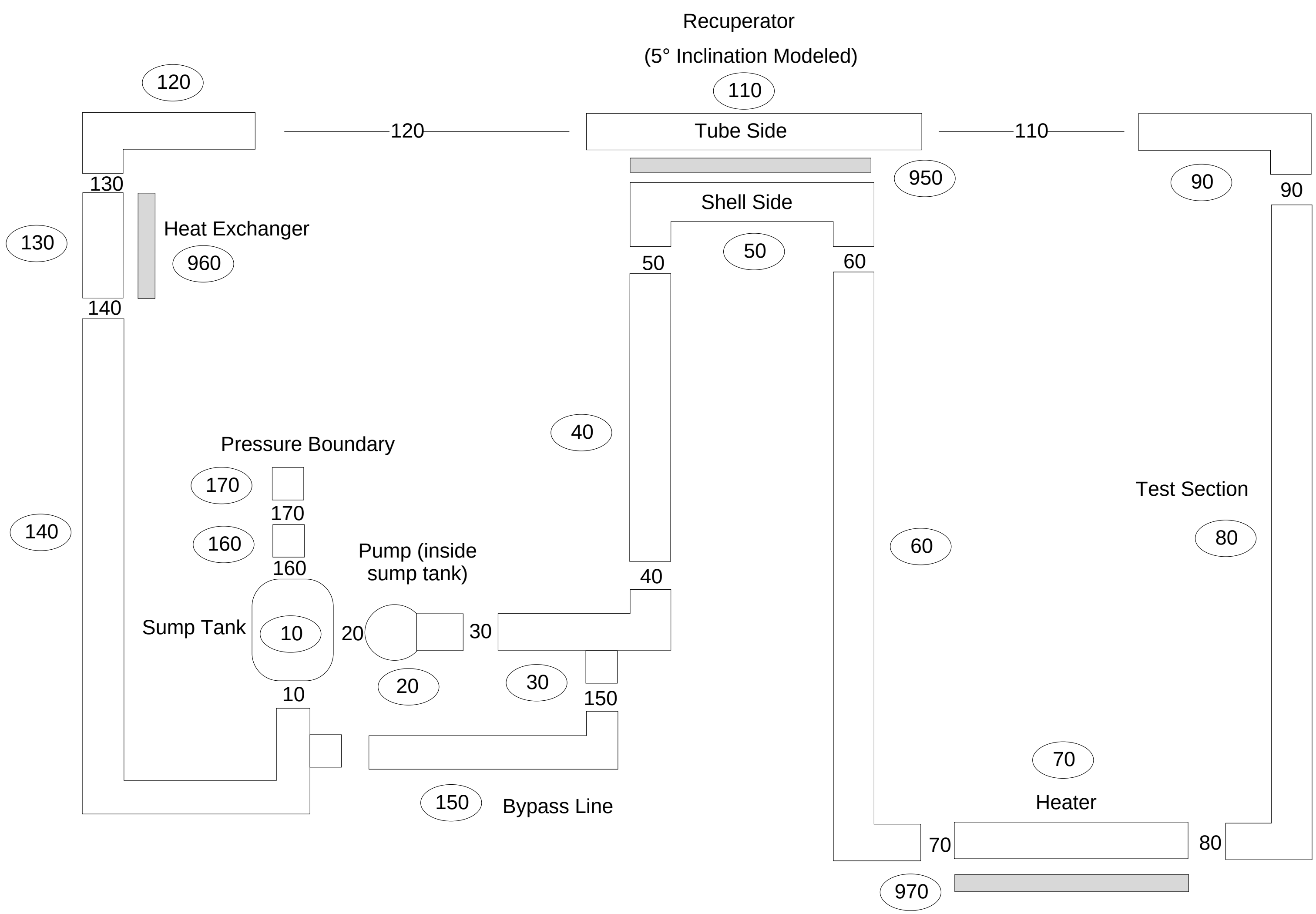

| | |
|---|---|
| velocity | 0.6 m/s |
| diameter | 0.0525m |
| diffusion coefficient | 1E-9m^2/s |
| Oxygen concentrasion | 0.01ppm |
| Loop Length | 29.2m |

# *TRAC Modeling of DELTA Loop and Benchmarking with Test Data*

Status as of June 30, 2002

- Developed A TRAC model of the DELTA Loop
- The model reflects correct pipe sizes, elevations, and calculated loss coefficients
- The model has been checked and calculated to steady state at several different assumed mass flows and power settings
- DELTA Loop test data is being obtained to benchmark the TRAC model
- The TRAC model will then be updated to include trace species tracking for corrosion modeling
- TRAC will be used to support MEGAPIE safety studies

# DELTA Loop TRAC Model




Advanced Accelerator Applications AAA

# International and University Collaborations for LBE Technology Development

- International
  - CEA (France): CICLAD/DELTA corrosion tests coordination, Al-316L corrosion test specimens for DELTA delivered
  - MEGAPIE: recommendation of oxygen control strategy (to avoid liquid metal embrittlement) and LANL sensors; agreement to adapt TRAC to support safety studies
  - TECLA (EU): exchange of reports with oxygen sensor working group
  - FZK (Germany): oxygen control systems, GESA-treated 316L corrosion test specimens
  - RIT (Sweden): request of LANL oxygen sensors for natural circulation experiment (experimental data in return)
- University
  - UNLV: test plan, delivery and inspection of LBE loop; project supports
  - MIT: Si-Fe alloys for DELTA test
- Visits Received at DETLA Loop in FY02
  - 13 (7 international; 6 universities; total 31 persons)

# FY03 R&D High Priority Tasks

- Corrosion analysis of test specimens
- Improvement of oxygen sensors for lower operating temperature
- Test and improvement calibration and control systems
- Corrosion modeling (including TRAC) and comparison with data
- Effects of (surrogate) spallation products on coolant chemistry and corrosion
- Thermal hydraulic testing
- Development of plans to measure thermodynamic and transport properties relevant to LBE technology
- International (FZK, CEA/CNRS, MEGAPIE, TECLA, JNC, RIT etc) and university (UNLV, MIT) collaborations